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Requirement c

Optimal Imaging for Treaty Verification

SL12-OptImg-PD2Nc

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1. INTRODUCTION

Future arms control treaty verification regimes may use radiation imaging measurements to confirm and track nuclear warheads or other treaty accountable items (TAIs). This project leverages advanced inference methods developed for medical and adaptive imaging to improve task performance in arms control applications. Additionally, we seek a method to acquire and analyze imaging data of declared TAIs without creating an image of those objects or otherwise storing or revealing any classified information. Such a method would avoid the use of classified-information barriers (IB).

2. TECHNICAL APPROACH

The medical tasks of detecting, locating, and classifying the radiation signatures from a medical patient as indicators of either threatening or benign conditions is adaptable to similar treaty-verification tasks. Based on experience with related radiation imaging systems for medical applications, we expect to achieve superior performance by use of task-based techniques, i.e. analyzing raw image data instead of reconstructed images. Generally speaking, this is because image reconstruction algorithms introduce noise and correlations that degrade the available information.

In addition, these task-based techniques have the potential to address the important issue of information sensitivity in arms control applications. Key aspects of task-based

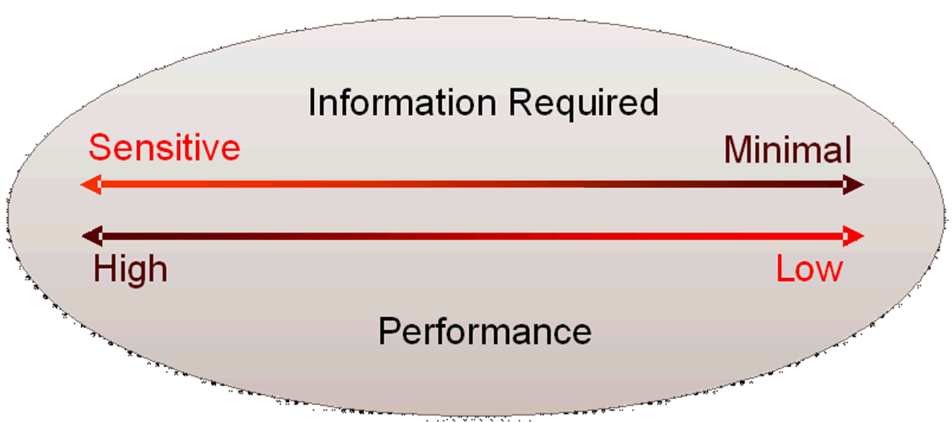


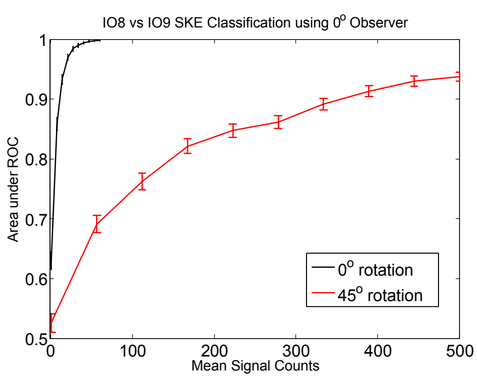
Figure 1: Within the task-based imaging framework, we investigate different observer models that occupy different points in this notional trade space between information required and analysis performance.

methods in nuclear medicine are: (1) data from individual radiation-detection events can be processed as they are measured, which removes the need to store those data for future analysis, (2) the resultant processed information cannot be analyzed to recreate those original event data, and (3) the resultant processed information cannot be analyzed to extract classified spectroscopic or geometric information about the object being measured. The way in which the data is processed (the observer model or OM) could itself use sensitive information in order to achieve better performance; the choice of OM will therefore involve a tradeoff as depicted in Figure 1. In a treaty scenario, the combination of these properties could enable the use of spectroscopic imaging hardware without an information barrier to prevent the collection or disclosure of classified information.

3. STUDIES AND RESULTS

Our investigations use the ORNL/SNL fast neutron coded aperture imager as a model. In task-based imaging, we define the performance of an imaging system or image-analysis methodologies in terms of how well they can accomplish the relevant task, i.e. the purpose for acquiring the image data. At this stage in the project, the task is to distinguish between various unclassified test objects, such as the INL inspection objects. We use detailed Geant4 simulations of the objects and the imager to build the algorithms and study their performance.

For a given detector, object, and task at hand, there are many ways to use the information available from the measurement to perform the task. These various methods are called Observer Models (OMs). An example of a study comparing multiple OMs is shown in Figure 2, which addresses the importance of nuisance parameters (things that affect the measured data but are not relevant to the question at hand), such as the position and orientation of the object. Other OMs that have been studied include multiple versions of a Hotelling observer.



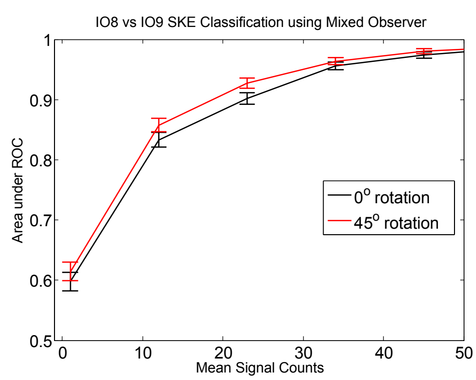


Figure 2: These plots show the area under the ROC curve metric as a function of the number of analyzed simulation events, for several OMs designed to distinguish two INL inspection objects (IO8, IO9). In the left plot, an OM that knows the object orientation perfectly performs well, while an OM that assumes the incorrect orientation performs poorly. In the right plot, the OM marginalizes object orientation by integrating over the possible values; performance is almost identical for objects at the two orientations. These studies do not include background or other realistic features; they are intended to illustrate the importance of dealing properly with nuisance parameters, or systematic uncertainties, in the techniques under study.

Ongoing work includes further improvements to and validation of the simulation models, especially the detector response; further study of the relative importance of various nuisance parameters to the verification task; and development and characterization of more OMs that represent different points in the trade space of Figure 1.

4. CONCLUSIONS

A new class of techniques is under development for the use of radiation imaging in the context of arms control treaty verification. These techniques, modeled on successful approaches in medical imaging, are expected to outperform standard image reconstruction for well-defined tasks; they also have several features that may allow sensitive information collected in such measurements to be protected without electronic information barriers.